SEISMIC QUALIFICATION OF CIVIL ENGINEERING STRUCTURES - Temelín NPP

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Abstract
The paper provides basic information on Temelín NPP seismic upgrading programme, including description of the main structural changes that were performed in order to ensure sufficient seismic capacity of civil structures. Information on seismic design basis, rules accepted for seismic classification of civil structures and methodologies for seismic reevaluation will be given.

1.1 Introduction

The present Section contains basic information about input data and methodology used for evaluation of Temelín NPP civil structures. The description is made for the existing valid condition as it is listed in POSAR report for the both units. The original design of this plant assumed a lower level of the locality seismic hazard in compliance with seismological surveys carried out which where then available.

After a decision was made to build-up two units of the power plant a new updated seismic input was elaborated which completely respects recommendations of the IAEA and which is based on a minimum value of acceleration in horizontal direction PGA_{HOR} = 0.1 g at free field level for SL-2. In relation with the new seismic project brief a new qualification of the structures, components and systems classified in category 1 of seismic resistance was carried out.

Since the Czech Republic has no technical standards for evaluation of nuclear power plants seismic resistance of its own, a detailed methodology was elaborated [3] which comprises principles of the seismic resistance evaluation and which is based on the IAEA guides and on common practice in countries with advanced nuclear power engineering [4].

1.2 Seismic Classification Temelín of Civil Engineering structures

The principles of the seismic classification are in accordance with IAEA regulations. The civil structures of category 1 are divided into two groups. In the first group the structures are classified which must perform the below functions related with provision of nuclear safety of a nuclear power plant unit:

- assurance of reliability of structures, technological systems and equipment components, damage or functional failure of which could cause emergency conditions.
- assurance of performance of other functions at and after a seismic event: reactor safe shut-down and its preserving in a safe condition, monitoring of critical parameters and provision for residual heat for a period of min. 72 hours.

- assurance of protection against radioactive matters and radiation propagation into nuclear power plant neighborhood within limits of the highest allowable leaks valid for emergency conditions.

For this group of structures their seismic resistance up to the SL-2 level is required.

In the second group the civil engineering structures are classified which are not classified in the first group and which satisfy the following conditions:

- they form a part of building structures in which handling with fresh fuel assemblies before their loading into reactor occurs,
- they form a part of building structures in which handling with low- and medium-radioactive liquid media occur, even when it is proven that the possible leaks of these matters into ambient environment at failures due to a seismic event will not cause exceeding of limit doses defined as limits for the given locality.

For this group of structures their seismic resistance up to the SL-1 level is required.

Table 1 **Summary of Seismic Categories for Civil Structures of the Temelín NPP**

Building No.	**Description**	**Required Seismic Resistance**
800/01-06	Reactor building	SL-2
803/01, 03	Reactor building ventilation stack	SL-2
807/01, 02	Air pressure vessels foundations	SL-2
586/01-03	Cooling pools with spraying systems	SL-2
586/4	Switchboards for technical water systems	SL-2
588	Ducts for technical service water systems piping	SL-2
594/01	Water treatment for technical service water systems	SL-2
442/01-03	Diesel generator, pumping and compressor stations	SL-2
445/01-03	Diesel oil handling	SL-2
350	Cable ducts	SL-2
352/02	SMS sensors building	SL-2
801/01	Auxiliary building (fresh fuel assemblies storage)	SL-1
801/01	Auxiliary building (wardrobes and laboratories)	SL-1
801/03	Auxiliary building (RA media treatment station)	SL-1
803/02	Auxiliary building ventilation stack	SL-1

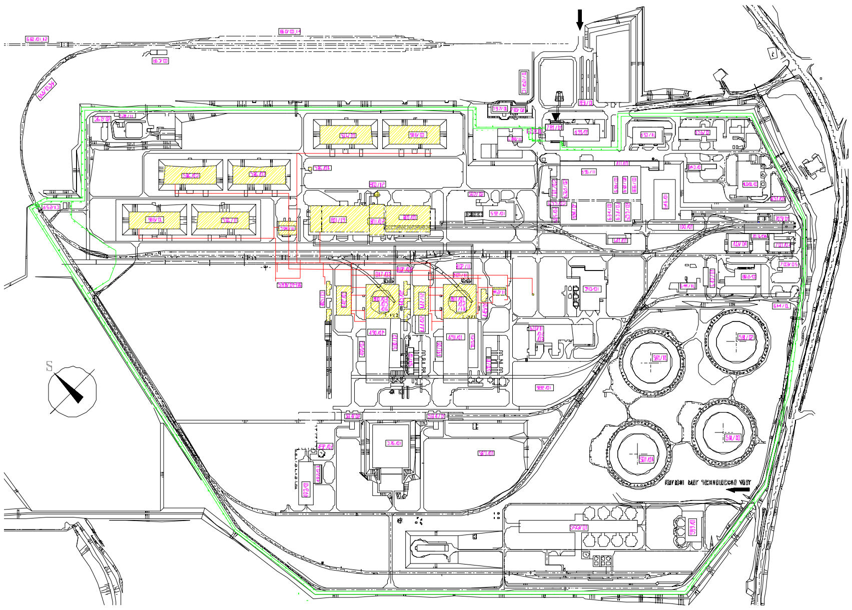


Fig. 1 **Temelín site plan**

- yellow colour – civil structures of the 1st seismic category
- red lines – underground pipe and cable ducts of the 1st seismic category

1.3 Seismic INPUT Data

In compliance with the IAEA guides [1,2] ,two design earthquake levels SL-1 and SL-2 are defined for the Temelín NPP. This solution is also in accordance with the new edition of IAEA regulations [8,9]. A recurrence period of SL-2 is assumed once per 10^4 years, for SL-1 level it is once per 10^2 years. For these levels the following peak accelerations are valid:

Table 2 **PGA Values for SL1 and SL2 Earthquake Levels for the Temelín NPP**

SL-1		SL-2	
Horizontal [g]	Vertical [g]	Horizontal [g]	Vertical [g]
0.05	0.035	0.10	0.07

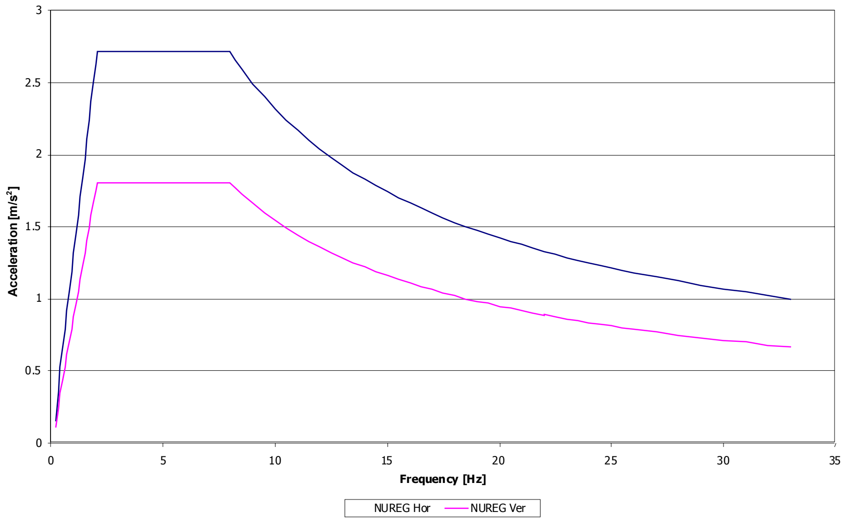
With view to the fact that the Temelín NPP is situated in an area of low seismic activity and no earthquake records directly from the locality are available and in compliance with the IAEA documents [1,2], the following two approaches are eligible:

- use of a set of natural accelerograms recorded in the areas with similar conditions,
- use of standard broadband spectra, for which synthetic accelerograms are generated.

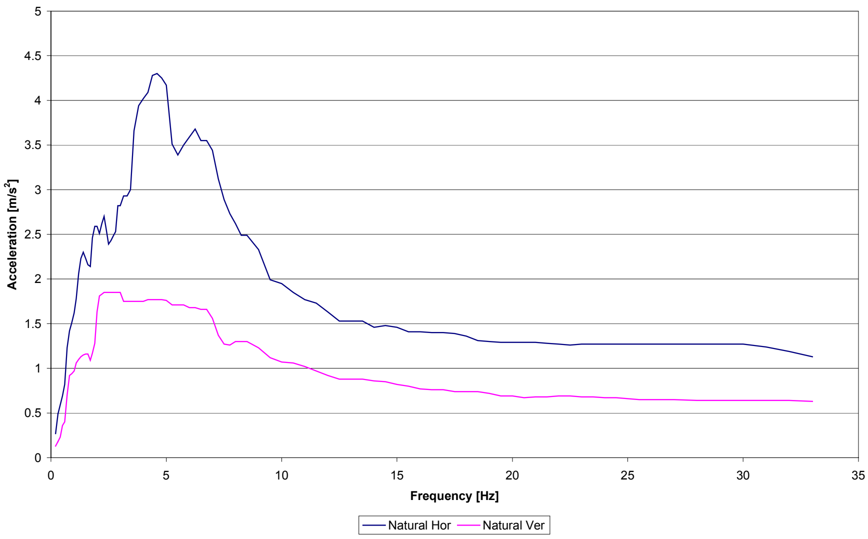
A selection of natural accelerograms for seismic analyses of the Temelín Nuclear Power Plant was carried out in 1982 and then modified in 1986 and 1993. Finally, the set of five three-component accelerograms was selected for the design purposes.

Subsequently, the response spectra were calculated from these accelerograms. The resulting enveloped spectra for those derived from natural records for 5% damping are demonstrated in Figure 3.1 including their comparison with the standard NUREG/CR-0098.

Based on the recommendation of the State Office for Nuclear Safety in 1996, an alternative possibility of a project brief utilizing NUREG/CR-0098 standard spectra (rock base and 84% level of non-exceeding probability) was accepted for the Temelín Nuclear Power Plant.



(a) NUREG/CR-0098 Spectra (PGA = 0,10 g)



(b) Seismic Response Spectra Calculated from Selected Natural Accelerograms (PGA = 0,10 g)

Fig. 2 Seismic Response Spectra (SL2) Used for the Temelín NPP Site

1.4 Calculation METHODS of Civil Engineering Structures for Seismic Analyses

1.4.1 Calculation Methods

For analyses of all civil engineering seismic category 1 structures the spatial (3D) models were created using the computer software based on finite element method. Only programs approved and verified by the State Office for Nuclear Safety were used for analyses of structures important to safety (NISA, STARDYNE, ABAQUS, SAP).

In a majority of cases the analyses were carried out for seismic loads represented by acceleration time histories, either using direct numerical integration or modal decomposition.

For evaluation of some specific partial structural sections the response spectrum method was also used. The equivalent static load method was used for those parts of structures only that do not form global bearing structures.

A prevailing method of seismic analysis was the method of modal superposition when the seismic load is represented by the acceleration time histories. Number of eigenvalues used for the calculation was controlled by the cumulative modal mass in such a way to reach for an each direction at least 80% of the total modal mass of the model.

For evaluation of structural elements the national Czech standards for design of steel and reinforced concrete structures [5,6] were applied. These standards are based on the limit state method.

All the analyses were carried out as linearly elastic ones. In reasoned cases the accepted methodology permits to use the limited ductility that enables to take into account plastic reserves of the structure when subjected to the load combinations including the SL-2 loads. This limited ductility was used exclusively for massive concrete heavily reinforced elements of structures exposed mostly to bending with which a ductile mode of failure can be assumed.

1.4.2 Dynamic Soil-Structure Interaction

The shear and longitudinal wave velocities of the subsoil strata were measured by the refraction method in 7 profiles in the site in 1992. The depth of these profiles was from 180 to 360 m. These measures confirmed that below the foundation level of all seismic category 1 structures the velocity of shear waves is higher than 1100 m/s. Therefore, based on the common engineering practice [4], it is not necessary to consider interaction of building structures with their subsoil. Actually, these velocities below the foundation level vary within the range from 1400 to 2530 m/s. Hence, the calculation models may be considered as fix based.

Nevertheless, in case of the reactor building when the floor response spectra were calculated the soil was conservatively modeled using the equivalent springs as recommended in ASCE 4-86 [4]. This procedure led to the result that the floor spectra are conservative in comparison with those obtained for the fix base model.

1.5 Calculation of Floor Response Spectra

The floor response spectra were calculated based on the spatial 3D structural models. The time responses were calculated gradually for individual sets of natural accelerograms. Alternatively, the synthetic accelerograms generated from the enveloped response spectra were used.

The nodal points for calculation of time histories of acceleration were selected in such a way that their seismic movements express imply for total seismic response of the floor including all possible bending and torsional modes (usually about 10 selected nodes on each floor). The floor response spectra were calculated at these selected nodes for the following damping values: 1, 2, 3, 4, 5, 7, 10 %. It should also be noted, that for peak broadening (±15% of the peak frequency) and smoothing the standard methodology as given in RG 1.122. [7] was used.

The resulting floor spectra were determined as an envelope for statistic level median+1 sigma.

Next figure shows the typical example of calculated floor response spectra for reactor building.

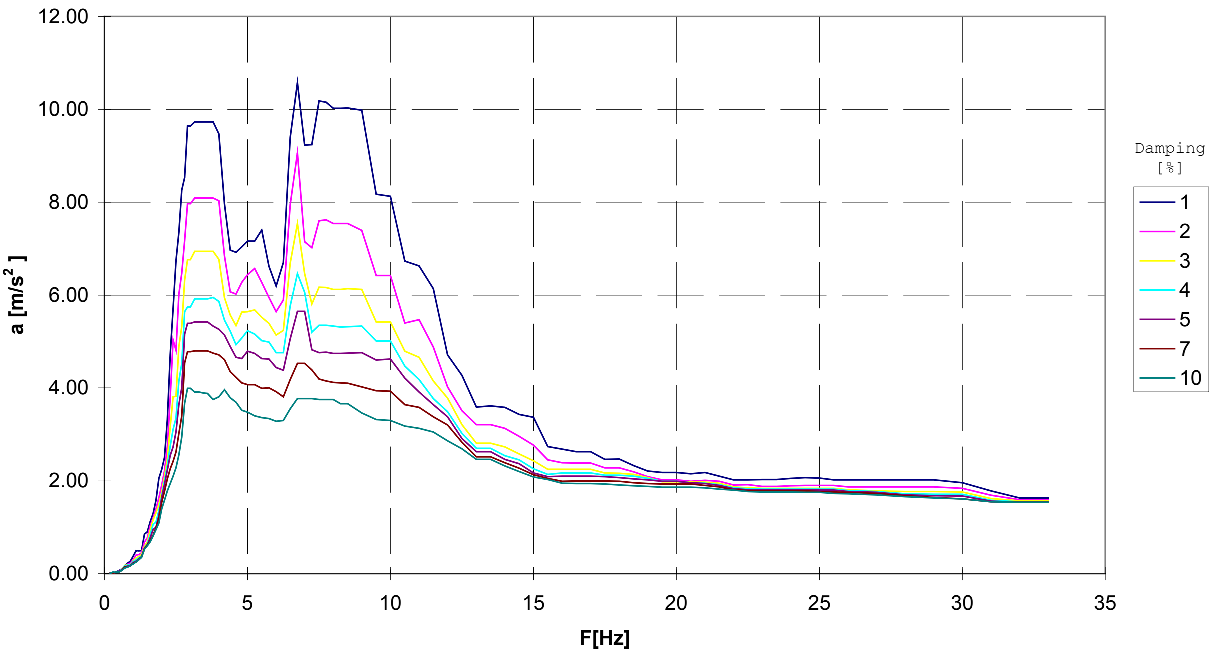


Fig. 3 Reactor Building – Floor Response Spectra - Elevation +13,20 m – Horizontal Direction

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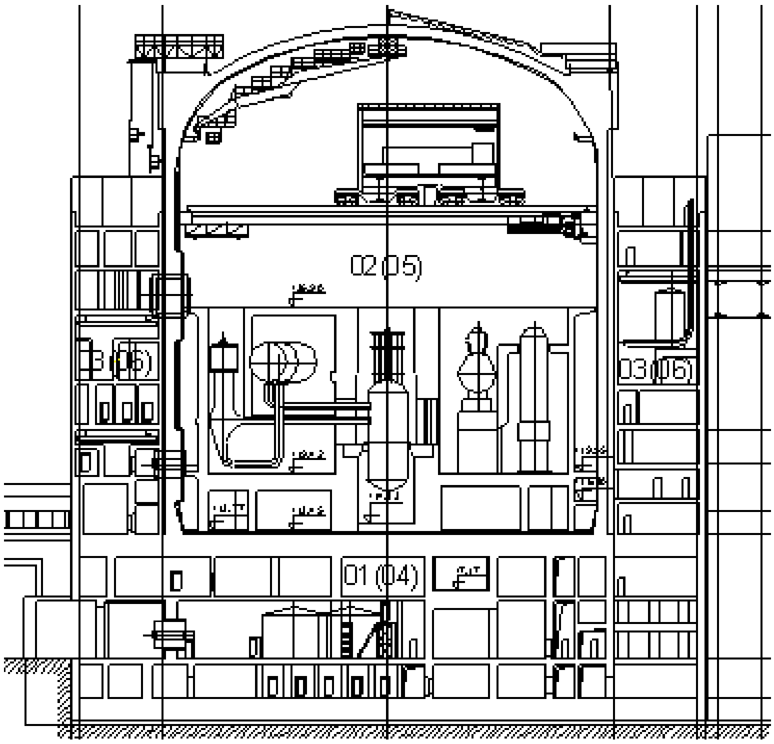
1.6 Results of the seismic qualification of buildings in the Temelin Nuclear Power Plant

This part briefly describes results of the seismic qualification of buildings and the relevant improvements, which were necessary to be implemented for assurance of required seismic resistance.

- **Reactor Building**

The reactor building is the massive structure from reinforced concrete with good resistance against seismic effects. The containment is made from prestressed concrete. The design fully complies with loads created by seismic effects and none implementation of the structural upgradings is necessary.



- **Reactor building ventilation stack**

The stack is from steel. It is anchored in the roof of the reactor peripheral building. The stack provides sufficient resistance and none improvements are necessary in order to improve its seismic resistance.

- **Air pressure vessel foundation**

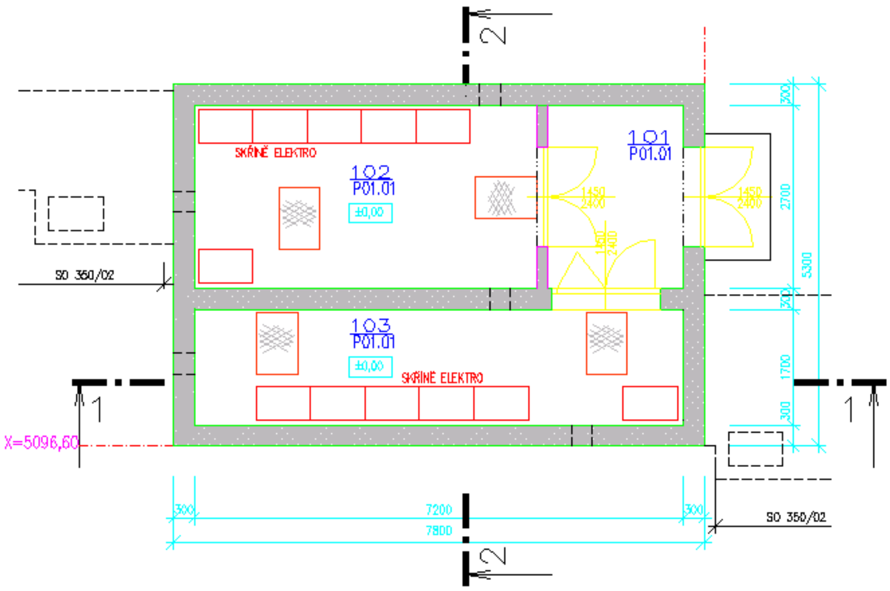
It concerns foundation from reinforced concrete blocks for anchorage of air pressure vessels. Seismic capacity is sufficient and none structural improvements are necessary.

- Cooling pools with spraying systems

They are outdoors open pools. Their seismic resistance is sufficient and none improvements of design are necessary.

- Switchboards for technical water systems

It concerns small masonry building for switchboards with underground cable room. Insufficient seismic resistance was identified by analyses. This building was not provided by mutual connection of individual walls at the floor and roof levels. Insufficient stiffness of the roof level was caused by inappropriate utilization of prefabricated elements with inconvenient details for connections. In order to assure required seismic resistance full reconstruction and stiffening was performed. The stiffening at the floor level was added. The original roof structure was removed and replaced by new monolithic structure from reinforced concrete, which provides sufficient space stiffness of building particularly in details concerning bonds with supporting walls of building. The seismic resistance of this building after reconstruction is sufficient enough and fully complies with all requirements for the 1st category of the seismic resistance buildings.

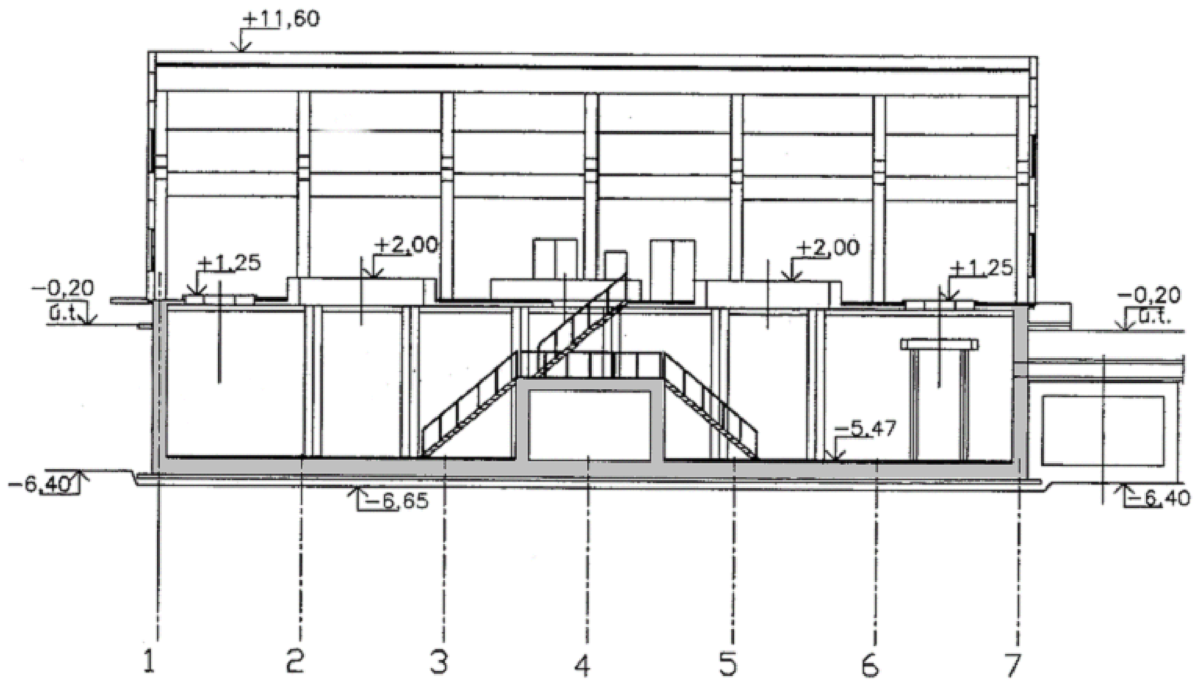


- **Ducts for technical service water systems piping**

The seismic resistance of underground structures of piping ducts from reinforced concrete is sufficient and none improvements are required.

- **Water treatment for technical service water systems**

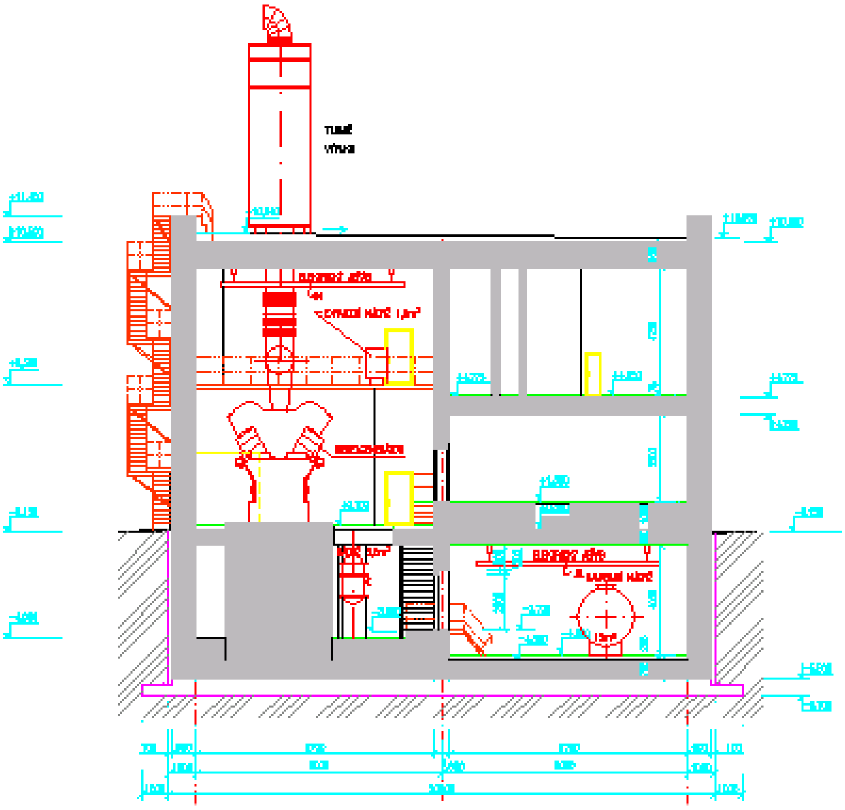
The lower part of the building is the monolithic structure from reinforced concrete. The supporting structure of the surface hall is performed from prefabricated elements. The analyses discovered good load capacity of the lower part of building. However the resistance of the prefabricated upper part is insufficient from the point of view of the seismic effects. This building accommodates none safety systems. It serves for technical service water filtration where certain amount of water is withdrawn from the operating systems for filtration. The filtration equipment operation is not required in course and after the seismic event. The classification of the building as the 1st category of seismic resistance building was due to the fact that branches from all three independent technical service water systems lead into the building. Thus in case of the building failure it was necessary to prevent concurrent release of water from all three systems. This requirement was ensured by reconstruction of the seismic resistant lower part of building in such way, that in case of piping rupture the lower part of the building will act as the retaining sump to prevent water release into the connected piping ducts.
In case of rupture of branches from the technical service water systems the retaining sump in the lower part of the building will be filled up to the water level in the cooling pools with sprinkling (interconnected vessels) and further release of water can not occur.
The reliable functions of all the technical service water systems is provided in course of seismic event and after this event by such reconstruction even in case of the upper prefabricated part of building failure.



- Diesel generator, pumping and compressor stations.

This building is massive structure from the reinforced concrete with very good resistance against the seismic impacts. Therefore none reconstruction was necessary for the whole supporting structure.

However the local stiffening of the floor structure housing the pumping station was performed in order to improve resistance for the seismic anchorage of the technological equipment into the building.



- Diesel oil handling

It concerns structure from reinforced concrete for tanks. The structure resistance against the seismic impacts is sufficient enough and none reconstruction is necessary.

- Cable ducts

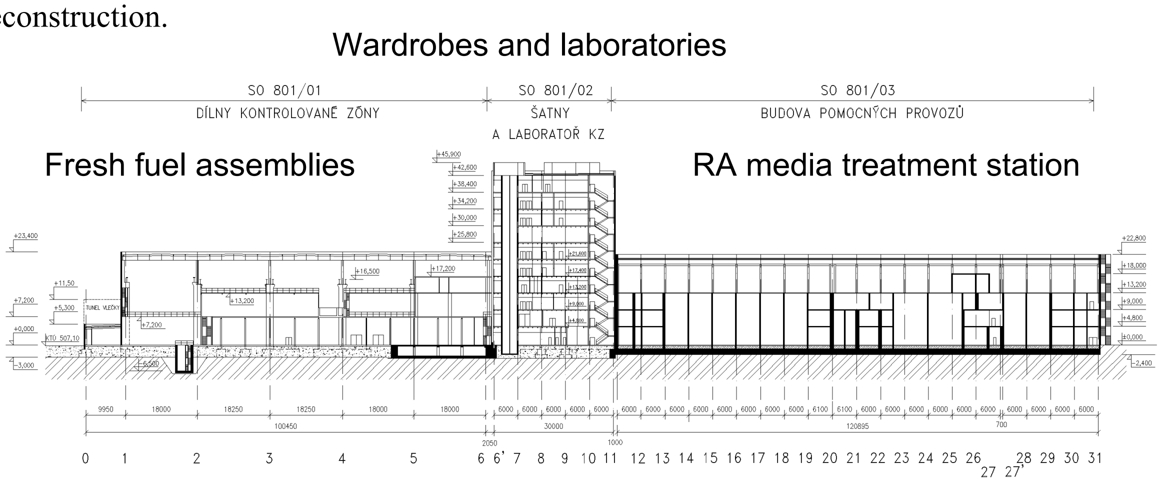
The underground structure of the cable ducts provides sufficient seismic resistance against the seismic impacts.

- SMS sensors building

It concerns simple sump from reinforced concrete housing seismic monitoring system sensors. The seismic resistance of the sump structure from the reinforced concrete is fully sufficient.

- **Auxiliary building (fresh fuel assemblies)**

It concerns the hall with steel structure. It was identified by analyses that in order to assure required seismic resistance the steel structure need to be stiffened in part of the vertical bracing in raw No 6. Required strength and rigidity was achieved by welding of steel bands into the diagonal rods of the bracing system and by shortening of the lengths of diagonal bracing rods. The seismic resistance is fully sufficient after implementation of this reconstruction.



- **Auxiliary building (wardrobes and laboratories)**

Skeleton of the building is made from steel. The building was classified into the 1st category of the seismic resistance due to its possible seismic interactions with surrounding building of the 1st category. Thus it is necessary to prevent the full collapse of the supporting structure. The sufficient seismic resistance was identified by analyses. Therefore reconstruction is not required.

- **Auxiliary building (RA media treatment station)**

Part of this building at the level +0,00 with massive structure from reinforced concrete used for storage of liquid radioactive waste is classified in the 1st category of the seismic resistance. Analyses identified that the seismic resistance of the building is sufficient enough and none reconstruction resulting from the requirements on the seismic resistance is necessary.

- **Auxiliary building ventilation stack**

The vent stack is from reinforced concrete with 100 m high, which is founded on the circular foudation plate. The stack is classified in the 1st category of the seismic resistance only due to possible interactions with surrounding buildings. Proof of the sufficient seismic resistance was provided by analyses.

2 References

[1] Safety Series 50-SG-S1, Rev.1 „Earthquakes and Associated Topics in Relation to Nuclear Power Plant Siting“. IAEA, Vienna, 1991.

[2] Safety Series 50-SG-D15 “Seismic design and qualification for nuclear power plants”. IAEA, Vienna, 1992.

[3] Guidelines for evaluation of safety documentation of the Temelin NPP. Volume 3 “Building structures, technological systems and equipment components” (in Czech). Report No. rep01-96.ujb, Revision 4. Stevenson and Associates, Pilsen, 1996.

[4] ASCE 4-86 “Seismic Analysis of Safety-Related Nuclear Structures“. ASCE, New York 1986.

[5] ČSN 73 1201 „Design of Concrete Structures“ (in Czech).

[6] ČSN 73 1401 „Design of Steel Structures“ (in Czech).

[7] US NRC RG1.122 “Development of Floor Design Response for Seismic Design of Floor Supported Equipment or Components. Revision 1. U.S. NRC, Washington DC, 1978.

[8] NS-G-3.3 Evaluation of Seismic Hazards for Nuclear Power Plants. IAEA, Vienna

[9] NS-G-1.6 Seismic design and qualification for nuclear power plants. IAEA, Vienna 2003

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